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# SOME INVESTIGATIONS INTO METAL MATRIX COMPOSITE LEAF SPRING

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***Abstract:*** Laminated and helical springs are the suspension components which are used in light and heavy commercial vehicles. The latest research in automobile industries shows that most of the researchers work on composite material to manufacture automobile components. Automobile components like piston, brake drum, connecting rod and valve stem are manufacture with composite material due to these provide light weight and similar strength. Reducing weight and maintaining strength of component is major research issue these days. Metal matrix composite (MMC) is composite material which uses two or three material, one should be metal, other material can be compound, ceramic or metal which provide complete strength for the reinforcement. In many applications, the metal matrix composite mostly use lighter metals such as aluminium, magnesium, silicon carbide, boron carbide and titanium which provides desire strength. Metal Matrix Composites have been used in various industries including automobile industry because of their light weight and good strength. From literature it was seen that most of the research has been carried out on mechanical properties, shape optimization and failure behaviour by experimental and finite element approach on composite leaf springs made of E-Glass/Epoxy material. A small gap has been found to manufacture and study a leaf spring based on metal matrix composite material. It was also found that carbon/epoxy composite and aluminium and boron carbide based composite is best suitable for applications requiring low stresses, stiffness and weight reduction than other composite materials. Present study attempts to investigate the applications of these composites in the leaf spring. So for present study rear leaf spring of Tata Ace (mini truck) made of EN45A spring steel was considered. Leaf spring with Aluminium and boron carbide based composite was manufactured by stir casting technique and was analyzed experimentally. MMC based leaf spring under stress analysis, static test, test for load rate and hardness test as per the standards - IS 1135: 1995 (Laminated Springs assembly for automobiles) and SAE (HS - J788 - Manual on Design and Application of Laminated Springs) were performed. For experimental testing leaf spring testing machine was used that was capable of performing deflection and static test. The evaluation of EN45A steel and metal matrix based composite leaf spring shows that the metal matrix composite spring has lower stresses and less sagging. It was seen that composite leaf spring posses better mechanical properties and less weight than manganese traced spring steel currently in use.

***Keywords:*** Composite leaf spring, Spring Steel, Boron carbide, Metal matrix composite, IS 1135:1995.

## 1. INTRODUCTION

Metal matrix composite are used in automobile industry to manufacture interior, exterior, chassis and power transmission components. Exterior automobile parts like chassis and suspension components are the major application of metal matrix composite. Demand of metal matrix composite is also increasing in medium commercial vehicles and this may also increase to light commercial vehicle and mid segment cars. Due to increase in demand of better fuel efficient vehicles, light weight components and parts consolidation are the major issue to increased the demand of metal matrix based components in the automobile industry. Metal matrix composite provides design flexibility which pushes the automobile market towards composite based components. New innovation, experiment and numerical analysis may help to develop new automobile component based on metal matrix composite material.

Automobile manufacturer turning to light metal solution, aluminium engine block, suspension components, body panels and frame members are increasing common, in addition to the use of magnesium in components such as instrument panels, valve covers, transmission housings and steering column components. Composites can be utilized for vehicle suspension with substantial weight savings.

A metal matrix composite (MMC) is composite material which use two or three material to form new metallic bond material. Aluminium, magnesium, boron carbide, silicon carbide titanium and alumina are mostly used to manufacture metal matrix composite based automobile component. In very high temperature cobalt and nickel alloys are mostly used. When more than two materials are used to manufacture composite material that material is known as hybrid composite material. In metal matrix composite second material is reinforced in first material. When second material is use as reinforcement, it does not force to make new material, but also used to change the mechanical and thermal properties of the exiting material such as wear resistance, and thermal conductivity. The second material (reinforcement) can be metal, ceramic or organic. In manufacturing of metal matrix composite material, the use of advanced metal matrix micro and nano reinforced material not only reduce mass but can also improve strength and life.

Extrusion, forging and rolling like metal working technique may be used to form metal matrix composite material. The most widely used methods for the manufacture of metal matrix composite materials and composite parts are stir casting, centrifugal casting, squeeze casting and powder metallurgy. Metal matrix composite materials are excellent physical, mechanical and development properties of composite materials. These are mostly used in aircraft industry, marine industry, automobile industry and electronic and electrical industry.

## 2. LITERATURE REVIEW

Miracle (2005) showed that metal matrix composites (MMCs) can be widely used in the field of automobile, aerospace, thermal and structure industries. This study described that material and method used to manufacture metal matrix composite. It also described the application, technological feature and characteristics of the composite materials. [1]

Reference [2] described the affect of ellipticity ratio on performance of composite elliptical springs had been investigated by both experimentally and numerically. A series of experiments was conducted for composite elliptical springs with ellipiticity ratios ranging from one to two. Typical failure behaviour composite spring was analysed. This study showed that composite ellipiticity can be used for light commercial vehicle as well as for medium commercial vehicles. The analysis showed that elliptical ratio significantly affects the spring rate and failure loads.

Nie et al. (2007) examined $B_4C$ particles reinforced with 2024 aluminium alloy matrix composite were manufactured by mechanical hot extrusion process. The result showed the morphology, microstructure, yield strength and young modulus and ultimate tensile strength values of composite materials were enhanced significantly over the monolithic aluminium 2024 alloy. [3]

Prawoto et al. (2008) examined suspension coiled helical spring. Result described the materials performance, fundamental stress cross the spring manufacturing defects and failures behaviour. The failure behaviour showed the insufficient load carrying capacity, manufacturing defects such as delayed quench cracking and material defects such as excessive inclusion levels. Finite element analysis of stress distributions around typical failure initiation sites was also presented. Failures due to complex stress usage and chemically induced failure were also discussed. [4]

Fuentes et al. (2009) researched the premature failure of leaf springs used in medium commercial vehicle. Result showed that visual inspection of fractured parts, common failure behaviour, characterization of various properties, examining the leaf spring history and simulation tests perform on leaf spring. It also described that fracture occurred by a mechanism of mechanical fatigue, initiated at the area of the central hole, which suffered the significant mechanical stress levels. [5]

Reference [6] used finite element method to design and analysis carbon and glass fibers epoxy based composite drive shafts. Research paper described that one layer of carbon–epoxy and three layers of glass–epoxy with 90L, 45L and 0L was used. Result showed that while, change from the best to the worst stacking sequence, the drive shaft causes a loss of 46.07% in its buckling strength. Buckling strength which show the major interest over shear strength in drive shaft design. Due to change of carbon fibers winding angle from 0L to 90L, the loss in the natural frequency of the shaft was 44.5 %.

Mirzaeifar et al. (2011) studied the helical spring under the axial force both analytically and numerically. Elastic response of helical springs examined critically and in the analytically solution two approximations were study carefully. In the first approximation, both the curvature, pitch effects were assumed to be negligible, small pitch angles and helical springs with large ratios of mean coil radius to the cross sectional radius (spring index). [7]

Aggarwal (2012) described the improvement of the fatigue strength of material through shot peening technique to create compressive residual stress field in their surface layers. Results showed that by the use shot peening technique relaxed residual stress field varies and reduce the weight of spring Steel. Leaf spring used in automobile vehicles had been experimentally developed and simulating with industrial parameter. [8]

Mahndi and Hamouda (2013) used the fiber reinforced composite to form the new composite semi-elliptical suspension spring with principal of direction strength instead of shear direction. Typical behaviours of composite spring like compression, tension, torsion and cyclic tests were presented and discussed. A significant experimental examination of composite semi-elliptical suspension springs had been carried out. In this research three types of composites were tested glass/carbon/epoxy, carbon/epoxy and glass/epoxy. The result showed that the fiber type and ellipticity ratio significantly affect the spring stiffness. After 1.15 million fatigue cycles, composite semi-elliptical suspension spring's useful stroke was reduced by only 2%. The relaxation of the composite elliptic spring examined to be very sensitive to the compression rate. [9]

Rahman and Rashed (2014) examined the metal matrix composite of Al-SiC. Result showed the mechanical properties, microstructures and wear characteristics of silicon carbide (SiC) reinforced aluminium matrix composites (AMCs). Stir casting process was used to form composite material with varying SiC content (0, 5, 10 and 20 wt. %). Several parameters like tensile strength, wear performance, microstructures, vickers hardness of the composites were analysed. The results showed that 20 wt. % SiC reinforced AMC showed maximum hardness and tensile strength. SiC reinforcements in aluminium (Al) matrix increased hardness and tensile strength. Pin-on-disc wear test showed that reinforcing Al matrix with SiC particles increased wear resistance. Microstructure of composite material showed that cluster, non-homogeneous distribution of SiC particles in the Al matrix. And porosities were observed in microstructures and increased with increasing wt. % of SiC reinforcements in composite material. [10]

Krall and Zemann (2015) described the dynamic behaviour of Carbon Fiber Reinforced Particle (CRFP) leaf springs. The experimental specimen was prepared for the examination. In this study standard steel spring EN 45 was used as reference and three different composite springs were examined and compared. In this research two different methods impact test and shaker had been applied for the excitation of the components. The behaviour of spring element at different thermal conditions examined carefully. Therefore one of the test of composite leaf spring was examined at very low temperature. The composite spring design was calculated through lamination theory. Composite spring was formed through by hand lay-up and autoclave. [11]

## 3. PROBLEM FORMULATION

The extensive review of literature study reveals that many researchers carried out their research in aluminium with Silicon carbide, aluminium with magnesium, aluminium with boron and hybrid metal matrix field. Some of the researcher use metal matrix composite materials to make automobile components like piston, brake drum, connecting rod, valve stem and suspension parts etc. Aluminium MMCs can be produced by casting or by powder metallurgy. The significant work has been done on static analysis, properties of MMC, failure analysis and finite element approach also applied to analysis composite leaf springs.

From literature, a small gap has been found to manufacture and study a leaf spring based on metal matrix composite material. Aluminium 7075 and boron carbide based composite material used to manufacture leaf spring. Experimental test was used to analyse properties of metal matrix based leaf spring. It had assumed that new manufacture composite material will have better mechanical properties and less weight compare to traditional material used to make leaf spring. Aluminium 7075 with boron carbide metal matrix composite material used to manufacture leaf spring with following objective:-

i. To fabricate a leaf spring by using metal matrix composite material.
ii. To Analyse and compare of mechanical properties of leaf spring like - ultimate tensile strength and hardness.

## 4. EXPERIMENTATION

Aluminium 7075 and boron carbide of 600 mesh used to manufacture metal matrix based leaf spring. Boron carbide 600 mesh was used as reinforcement material. Table 1 and Table 2 below gives the composition and mechanical properties of aluminium and Table 3 Gives properties of boron carbide.

**Table 1**
**Chemical Composition of Aluminium 7075**

| *Element* | *Percentage* |
|---|---|
| Si | 0.40 |
| Fe | 0.50 |
| Cu | 1.2-2.0 |
| Mn | 0.30 |
| Mg | 2.1-2.9 |
| Cr | 0.18-0.28 |
| Zn | 5.1-6.1 |
| V | 0.0 |
| Ti | 0.20 |
| Bi | 0.00 |

**Table 2**
**Mechanical Properties of Aluminium 7075**

| *Property* | *Minimum* | *Maximum* |
|---|---|---|
| Yield Strength (MPa) | 130 | 145 |
| Ultimate Tensile Strength (MPa) | 240 | 275 |
| Elongation (%) | 11 | – |
| Hardness (HRB) | – | 150 |

**Table 3**
**Mechanical Properties Of Boron Carbide**

| *Property* | *Minimum* | *Maximum* |
|---|---|---|
| Density (g.cm$^{-3}$) | – | 2.52 |
| Melting Point (° C) | – | 2445 |
| Hardness (Kg.mm$^{-2}$) | 2900 | 3580 |

Muffle furnace was used to heat the aluminium to desired temperature. The mould of leaf spring was prepared by using Tata ace leaf spring. Aluminium was heated to temperature about 900° C in furnace. Alongside, Boron Carbide was also pre heated to the about 500° C temperature in order to remove the dissolved gases which would have otherwise resulted in the formation of blow-holes, during the casting process. Then the powder of boron carbide was added to the molten Aluminium 7075 alloy. The mixture of aluminium and boron carbide was stirred with the help of the stir casting machine at 900 rpm for about 10 minutes in order to ensure the proper and homogeneous mixing of the materials. When the materials got proper mixed, the molten mixture of aluminium 7075 and boron carbide was transferred to the prepared mould of the leaf spring. The molten mixture was thus allowed to solidify for some time. The solidified piece of leaf spring was then allowed to cool in air and withdrawn from the mould as shown in Fig. 1.

**Figure 1: Fabricated Al-$B_4$C leaf spring**

## 5. RESULTS AND DISCUSSIONS

The EN45 steel spring and Al–$B_4$C composite based leaf springs are tested in the leaf spring test ring machine. Both steel spring and metal matrix based composite leaf spring are tested

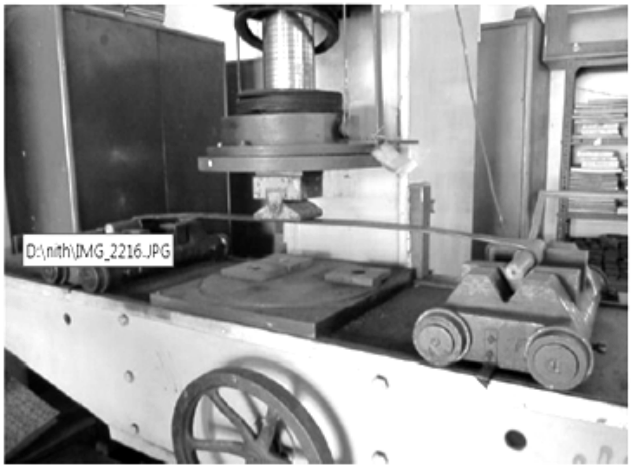


**Figure 2: Testing of leaf spring**

according to standard procedure recommended by SAE as shown in Fig. 2.

### 5.1. Deflection

In a test ring, the plunger is moved up to desired height so that fixture can be fixed. Leaf spring is mounted with help of fixture, the load is applied gradually and deflections are recorded. The load has applied at the centre of spring and deflection of the spring centre has record with gradually varying load. The spring has load from zero to prescribed maximum deflection which gives load v/s displacement curve as shown in Fig. 3.

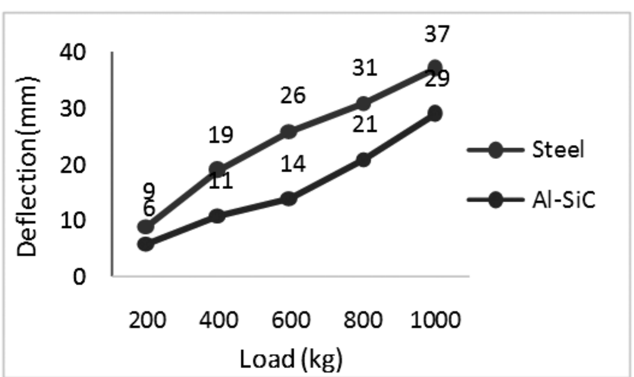


**Figure 3: Deflection of leaf springs at different loads**

### 5.2. Hardness

Hardness test was conducted on both type of leaf spring. Spring steel has hardness 90 BHN and composite leaf spring has 80 BHN hardness. Hardness test was performed on hardness testing machine as shown in Fig. 4.

**Figure 4: Hardness testing**

### 5.3. Tensile Strength

Tensile testing was performed on the universal testing machine. Under tensile test, a sample was subjected to controlled tension until failure. The results from the tensile test show a very close relationship between two springs as shown in Fig. 5.

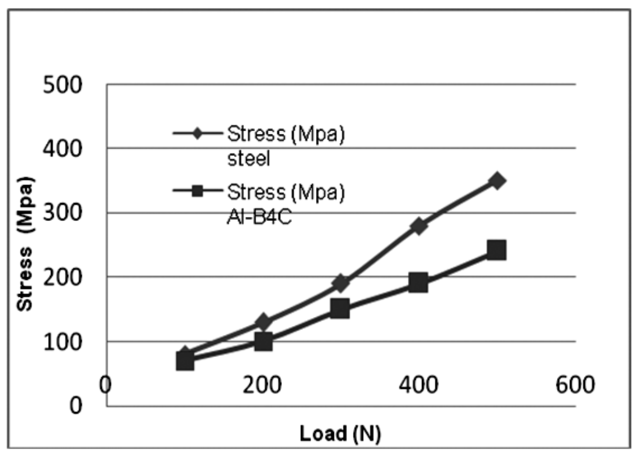


**Figure 5: Load v/s stress curve for steel and MMC spring**

## 6. CONCLUSIONS

Results show that the composite leaf spring is lighter in weight as compared to conventional steel leaf spring with similar design specification. But cost of the composite leaf spring is not effective over their steel counterpart. Composite leaf spring has more elastic stain energy storage capacity and similar strength to weight ratio as compared to steel spring. The comparison of spring steel and composite leaf spring shows that the composite spring has lower stresses, less sagging. It was seen that composite leaf spring posses compatible mechanical properties and less weight than spring steel currently in use. So, It is concluded that metal matrix based composite leaf spring is an effective replacement for the existing steel spring used in automobile vehicles.

## ACKNOWLEDGMENT

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